APPLICATION

FOR

UNITED STATES LETTERS PATENT

Be it known that we, Boris Y. Rozenoyer, residing at 89 Spring Street, # 3, Watertown, MA 02472 and being a citizen of United States; William Altergott, residing at 9 Hollis Street, Uxbridge, MA 01569 and being a citizen of United States; and Uday Kashalikar, residing at 11 Hearthstone Circle, Wayland, MA 01778 and being a citizen of United States, have invented a certain new and useful

METAL MATRIX COMPOSITE

of which the following is a specification:

Applicant: Rozenoyer *et al.*
For: METAL MATRIX COMPOSITE

RELATED APPLICATIONS

This application claims priority from Provisional Application No. 60/427,112 filed November 18, 2002.

GOVERNMENT RIGHTS

This invention was made with U.S. Government support under Contract Nos. NAS8-010019 and NAS8-02014 awarded by NASA, DAAE07-99-C-L016 and DAAE07-98-C-X015 awarded by the U.S. Army, DAAD17-02-C-0039 awarded by U.S. Army, and DAAH01-00-C-R070 awarded by U.S. Army. The Government has certain rights in the invention.

FIELD OF THE INVENTION

This invention relates to isotropic metal matrix composites with superior strength and high-temperature strength and stiffness retention features and a method of making the same.

BACKGROUND OF THE INVENTION

There is an ongoing search for new high strength and durable light weight materials. In one example, aluminum alloys have been used for both the engine head and block of gasoline engines to lower the weight of the engine and improve fuel economy. But, aluminum alloys do not have a sufficient stiffness or high-temperature strength for

diesel engines where the cylinder pressure can be at least twice that of a gasoline engine.

Metal matrix composites including ceramic reinforcement material in a metal matrix are an attractive alternative to metal alloys because of their high strength and low weight. Usually, the ceramic reinforcement material is in the form of powders, fibers, or whiskers.

Unfortunately, the typical tensile strengths for many metal matrix composites range from 30 to 70 ksi and, moreover, typical metal matrix composites lose a substantial percent of strength and stiffness at temperatures above 200°F. Wear resistance is also an issue in some known metal matrix composites.

Those skilled in the art have long sought a stronger and more durable metal matrix composite which exhibits high temperature strength and stiffness retention. See, for example, patent application No. PCT/US97/06323; U.S. Patent No. 5,394,930; EP 0754,659 B1; EP 0380,973; and U.S. Patent No. 5,141,683 all incorporated by this reference herein.

Sometimes, the ceramic powders of the metal matrix composite are first formed into a preform prior to infusion by the metal matrix material. Compaction and adhesive binders are usually used to make the preform. The paper entitled "Strength and Fracture Toughness of Aluminum/Alumina Composites with Interpenetrating Networks" (Prielipp et. al, Materials Science and Engineering (A 197, 1995, 19-30)), incorporated by reference herein, proposes sintering the ceramic powders to make a preform which can then be machined to provide near net shape parts and components. But, the highest tensile strength of the resulting metal matrix composite was 75 ksi which is not suitable for some applications. There have been reports of metal matrix composites with a

flexural strength exceeding 100 ksi but the tensile strength was less than 70 ksi.

SUMMARY OF THE INVENTION

It is therefore an object of this invention to provide a metal matrix composite which exhibits a higher tensile strength.

It is a further object of this invention to provide such a metal matrix composite which retains its tensile strength and stiffness at elevated temperatures.

It is a further object of this invention to provide such a metal matrix composite which exhibits good wear resistance.

It is a further object of this invention to provide such a metal matrix composite which has a low coefficient of thermal expansion.

This invention results from the realization that a more durable metal matrix composite with a higher tensile strength and which sufficiently retains its tensile strength and stiffness at elevated temperatures is effected by the use of a partially sintered reinforcement preform tailored to have a specified pore size, porosity, and flexure strength, by choosing substantially pure ceramic powders, and by carefully selecting the metal matrix material to be infused into the preform depending on the choice of the ceramic powders. Ceramic powders are partially sintered resulting in an isotropic reinforcement preform. The preform is infused with a metal matrix material by pressure casting, squeeze casting, or similar techniques resulting in an isotropic metal matrix composite with high strength, high stiffness, temperature resistance, a low coefficient of thermal expansion, and good wear resistance properties.

This invention features an isotropic metal matrix composite comprising a

reinforcement preform made by partially sintering ceramic particles and a metal matrix material infused into the preform. In one example, the resulting isotropic metal matrix composite has an ultimate tensile strength of at least 80 ksi in all directions. The tensile strength is typically greater than or equal to 100 ksi. Typically, the isotropic metal matrix composite has a high temperature strength retention of at least 85% up to 500°F and a high temperature stiffness retention of at least 95% at temperatures up to 500°F.

It is preferred that the preform has an average pore size of 1-5 microns, an average interconnected porosity 35-45 vol.%, a 100% open porosity, a flexure strength of greater than 7 ksi, and isotropic properties. It is also preferred that the ceramic particles are substantially pure (e.g., at least 99.0% pure).

The metal matrix material should be selected to prevent chemical reaction with the preform. The particles of the preform may be alumina or silicon carbide and the metal matrix material may be aluminum, aluminum alloys, magnesium, magnesium alloys, copper, and copper alloys. If aluminum is used, it should be substantially pure aluminum (e.g., 99.999% pure aluminum). One preferred aluminum alloy is aluminum alloy No. 201. Typically, the metal matrix composite has a coefficient of thermal expansion of less than 7.0 ppm/°F.

This invention also features a method of making a metal matrix composite wherein ceramic particles are partially sintered to form an isotropic reinforcement preform having an average pore size of between 1-5 microns, an average interconnected porosity of between 35-45 vol.%, an approximately 100% open porosity, and a flexure strength of greater than 7 ksi. The partially sintered preform is then infused with a metal matrix material.

Infusion may include subjecting the preform to the molten metal matrix material under pressure by pressure casting or squeeze casting techniques.

Typically, the isotropic metal matrix composite has an isotropic high temperature stiffness retention of at least 95% at temperatures up to 500°F, a high temperature strength retention of at least 85% up to 500°F, and an ultimate tensile strength is at least 80 ksi in all directions. The ceramic particles should be substantially pure and in one example were at least 99.0% pure. It is preferred that the metal matrix material is selected to prevent chemical reaction with the preform. The particles of the preform may be alumina or silicon carbide and the metal matrix material may be aluminum, aluminum alloys, magnesium, magnesium alloys, copper, and copper alloys.

BRIEF DESCRIPTION OF THE DRAWINGS

Other objects, features and advantages will occur to those skilled in the art from the following description of a preferred embodiment and the accompanying drawings, in which:

Fig. 1 is a three dimensional schematic view of an example of a metal matrix composite part in accordance with the subject invention in the form of a diesel engine combustion plate;

Fig. 2 is a three dimensional schematic view of two combustion plates joined within a cast aluminum alloy structure;

Fig. 3 is a three dimensional schematic view of an example of a reinforcement preform made by partially sintering ceramic particles in accordance with the subject invention;

Fig. 4 is a photomicrograph of the preform shown in Fig. 3; and

Fig. 5 is a photomicrograph of the preform shown in Fig. 3 after infusion by a metal matrix material.

DISCLOSURE OF THE PREFERRED EMBODIMENTS

Aside from the preferred embodiments or examples disclosed below, this invention is capable of other embodiments and of being practiced or being carried out in various different ways. Thus, it is to be understood that the invention is not limited in its application to the details of construction and the particular components set forth in the following description or illustrated in the drawings.

Metal matrix composite part 10, Fig. 1 is, in one particular example of this invention, a diesel engine combustion plate insert, but the invention is clearly not limited to this part alone. In this example, the ceramic reinforcement material used was alumina and the metal matrix material was aluminum alloy No. 201. Other possible ceramic reinforcement materials include silicon carbide, and other oxide and non-oxide ceramics. Other possible metal matrix materials include, *inter alia*, substantially pure aluminum (e.g., 99.999% pure or better), aluminum alloys, magnesium, magnesium alloys, copper, and copper alloys.

Two such parts 10, Fig. 2, in one example, were joined to be a part of cast aluminum alloy structure 12 to form a diesel engine head plate subcomponent. Inserts 10 may be joined to structure 12 by gravity casting or using processes such as brazing or diffusion bonding.

The construction of part 10, Figs. 1-2 begins with partially sintering ceramic

particles to form the reinforcement preform 14, Fig. 3. The ceramic particles used should be substantially pure (e.g., at least 99.0% pure) to prevent substrate strength deterioration due to undesirable chemical reactions at the ceramic/aluminum alloy metal interface during pressure casting. Preferably, preform 14 has isotropic properties, a pore size of between 1-5 microns, an average interconnected porosity of between 35-45 vol.%, 100% open (interconnected) porosity, and a flexure strength of greater than 7 ksi. Machining of preform 14 can take place before infusion as shown in Fig. 3 or after infusion with the metal matrix material.

In the example shown in Fig. 3, the Al_2O_3 preform 14 (99.1% wt) had a 100% open (interconnected) porosity, a median pore size of between 2.6-3.4 microns, an apparent porosity of 40.7%, a bulk density of 2.33 g/cc, a flexural strength of 7.8 ksi, and a thermal conductivity (200-550°F) of 0.06-0.04 W/cm-°K and a CTE (RT-550°F), of 3.39-3.71 10(-6)/°F.

Fig. 4 is a photomicrograph of preform 14, Fig. 3 showing the isotropic nature of the partially sintered ceramic (Al_2O_3) particles.

Surprisingly, one preform that met the above requirements is available from Coors Ceramics, Inc. (Golden, CO) and is typically used for filtering purposes and for kiln components. Other preforms that have an open porosity, an average pore size of 1-5 microns, an average interconnected porosity of between 35-45 vol.%, and a flexure strength of greater than 7 ksi made of alumina, silicon carbide and other ceramic materials, however, can be used. The molded shape of the preform will depend on the particular application.

To form part 10, Figs. 1-2, a metal matrix material is infused into the preform. In

one example, aluminum alloy no. 354 was melted and preform 14, Fig. 3 subjected to the molten alloy material under pressure by pressure casting or squeeze casting techniques. A photomicrograph of one isotropic resultant part or component (e.g., part 10, Figs. 1-2) is shown in Fig. 5.

The resulting metal matrix composite part had a flexural strength of 89.5 ksi, a thermal conductivity (200-550°F) of 5.52-6.46 W/cm-°K and a coefficient of thermal expansion (RT-550°F) of between 5.52-6.46 10(-6)/°F.

Additional examples resulted in ultimate tensile strengths (using a standard axial tension test methodology) of at least 80 ksi in all directions and even exceeding 100 ksi and all aluminum/alumina examples resulted in a metal matrix composite with a high temperature strength retention of 85% up to 500°F or even 550°F and a high temperature stiffness retention of 95% at temperatures up to 500°F. The measured coefficient of thermal expansion was less than 7.0 ppm/°F.

Preferably, the metal matrix material chosen (e.g., substantially pure aluminum, aluminum alloys, magnesium, magnesium alloys, copper, and copper alloys) do not react chemically with the material of the preform and vice versa.

As shown in Fig. 5, the metal matrix composite exhibits a dense, fully infiltrated structure with a clean matrix/ceramics interface and an absence of cast defects. The isotropic metal matrix composite of the subject invention has a high flexural strength and, at the same time, a low coefficient of thermal expansion and a high thermal conductivity. By changing the matrix alloy and final heat treatment of the metal matrix composite, it would be possible to achieve various combinations of mechanical and physical properties to meet different requirements for metal matrix composites in substantially variable

conditions. One positive feature of a continuous porous alumina preform (e.g., 100% open porosity) is its retention of strength at elevated temperatures and thus it can be utilized in service conditions where conventional high temperature aluminum alloys severely lose their strength. Also, the use of alumina reinforcement enables applications where high wear and light materials are needed.

The mechanical and thermophysical properties of the porous alumina preform and the corresponding metal matrix composite can be tailored to accommodate a wide range of service requirements for both structural and specific applications by slight variations in the porous substrate processing parameters.

If the preform is made of a partially sintered ceramic material, there is also no need to place the preform in the mold since it is able to retain its shape during all stages of the pressure casting process. An additional advantage of a porous preform is that it can be sintered and/or machined to a net shape prior to infiltration by the metal matrix material. Metal matrix composite shapes, such as plates, rods, bars and the like, can be pressure cast and then finish machined to the final shape. Moreover, it is possible to infuse multiple preforms at one pressure casting run to utilize the processing space of the pressure casting unit in the most efficient way. Therefore, the unit cost of the metal matrix composite pressure casting run can be substantially reduced by maximizing the volume of the metal matrix composites created per casting and by the elimination of expendable graphite molds.

To minimize fabrication costs, it is preferred to directly infiltrate the aluminum matrix alloy into the partially sintered reinforcement preform. Two experiments were performed to determine how to best infiltrate multiple large parts in a single pressure

casting to produce a fully homogeneous, pore-free metal matrix composite microstructure using free-standing porous ceramic performs.

Example 1

Five 8.75" diameter x 0.3" thick partially sintered reinforcement preforms made by partially sintering ceramic particles (Al_2O_3) were pressure cast within a simple graphite mold to keep the five preforms separated to facilitate casting demolding and metal matrix composite part separation and surface cleaning. All five preforms were successfully infiltrated and did not show any casting defects.

Example 2

A pressure casting chamber was equipped with two separate independent heating elements and separate thermocouples to record temperatures in both heating zones. Two presintered reinforcement preforms made by partially sintering ceramic particles were suspended using tubular stainless steel holders above the graphite crucible with the Al-2Cu metal matrix alloy charge. The crucible was placed on the top of the pneumatic piston allowing crucible movement in the vertical direction. After the chamber was evacuated, the aluminum alloy was melted and overheated to 770°C. At this temperature, the crucible with the melt was raised to the level and the porous preforms were fully immersed into the melt and the chamber was pressurized with argon to 885 psi. The temperature of the melt and the pressure were maintained at this level for 12 minutes and then the heater power was turned off and the crucible was lowered to its initial position to terminate a contact of the preforms with the pool of liquid alloy and to allow solidification of the matrix alloy within the free-standing porous preform plates. It took 15 minutes for full solidification of the alloy under positive pressure. After cooling to

room temperature and unloading a defect-free, near net shape metal matrix composite part as depicted in Fig. 1 was obtained.

The result, in any embodiment, is a metal matrix composite with a higher tensile strength and which retains its tensile strength and stiffness at elevated temperatures. The metal matrix composite of the subject invention exhibits good wear resistance and has a low coefficient of thermal expansion. By using a partially sintered reinforcement preform tailored to have a specified open pore size and a specific range of porosity and flexural strengths and by using substantially pure ceramic powders and by selecting the metal matrix material depending on the choice of the ceramic powders to be infused into the preform, a wide variety of different types of parts and components for a wide variety of applications is effected.

Although specific features of the invention are described and shown in some drawings and examples and not in others, this is for convenience only as each feature may be combined with any or all of the other features in accordance with the invention. The words "including", "comprising", "having", and "with" as used herein are to be interpreted broadly and comprehensively and are not limited to any physical interconnection. Moreover, any embodiments or examples disclosed in the subject application are not to be taken as the only possible embodiments or examples.

Other embodiments will occur to those skilled in the art and are within the following claims:

What is claimed is: